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SEED RAIN OF SELECTED SUBSIDENCE BASINS IN KARVINÁ REGION – PRELIMINARY RESULTS

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ABSTRACT

Overall amount and quality of seeds reaching the area is an important factor in the development of plant communities in each habitat. It can be a significant source of diversity in anthropogenically disturbed areas. This study is focused on the survey of seed rain in habitats of waterlogged subsidence basins of the Karviná region, induced by deformations of overlying rocks in the area of deep coal mining. The density, species composition and dispersal strategies of captured seeds were monitored using funnel traps with a 35 cm diameter, fixed at a height of 0.5 m. A vegetation study was conducted to compare seed rain with above-ground vegetation using the Jaccard similarity index. Over 11 000 seeds of 27 plant species were captured in total. Seed rain was dominated by *Salix alba* species. Seed density varied significantly within individual sampling plots (7–12380 seeds/m^2) with the average richness of four species. The diversity of above-ground vegetation was also low, with an average of 15 species per plot (100 m^2). Similarity between seed rain and above-ground vegetation of subsidence basins is 27.6 % and 52 % within the woody species community. It is evident that the seed rain of waterlogged subsidence basins contains species of floodplain forests and wetland vegetation. On the other hand, invasive and expansive species identified both in seed rain and above-ground vegetation can potentially endanger the development of the succession of these habitats. The analysis of seed dispersal also shows a significant proportion of species of arid and mesic habitats.

Keywords: Dispersal strategy; Karviná; Seed rain; Subsidence basin.

1 INTRODUCTION

Deep coal mining areas are characteristic for movement and deformation of the surface above the coal seams. The subsidence is gradually formed when the terrain settles, depending mainly on the thickness of the extracted deposit. Such human-exploited areas with transformed abiotic factors allow for the development of both ruderal, early successional community types, as well as natural, potentially rare and endangered communities [1]. Already formed and developing new plant communities are influenced by the availability of propagules [2], reaching area in the form of seed rain, representing the dispersion in time and space [3] at local to global level [4,5]. The estimation of seed rain of individual habitat is investigated mainly for the possibility of their restoration. Studies of this phenomenon are common in forest ecosystems [6], especially in tropical rainforests [7]. Studies of anthropically impacted landscapes are also numerous [3,8,9,10], but data on subsidence basins, a unique habitat, are missing. The aim of this work is therefore to provide basic information, such as composition, density, and similarity to above-ground vegetation, about the seed rain of these habitats.

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2 METHODS AND STUDY SITE

2.1 Study sites

The study took place on the subsidence basins in the Czech part of the Upper Silesian Basin with coal-bearing sedimentation of the Upper Carboniferous, which is stratigraphically divided into the Ostrava and Karvina formations [11]. After the deposits are mined, falling of the underground space roof and gradual geological fall lead to the formation of a subsidence basin. With the occurrence of impermeable geological layers at the surface, groundwater, precipitation, and surface water accumulate in the subsidence basins.

Two waterlogged subsidence basins in the Karviná region were selected for the study – U cesty and Kozinec. U cesty (49.8129506N, 18.4779606E) is a drainless subsidence basin of a small area (<1 ha) located in the Horní Suchá municipality, with a west bank rehabilitated by overburden. Kozinec (49.8670542N, 18.4906383E), situated in the Karviná district, northeast of the Doubrava municipality, is a large subsidence basin formed by the Karviná river and undrained depression – lake Kozinec. The current form of the area was created by a significant decline in the landscape and the expansion of the water areas by about 45 ha [12].

Measured at the closest weather station, southwest and west wind direction were prevailing in the year of the study. Detailed values are shown in Table 1 [13].

Table 1. *Wind direction percentage*

Subsidence	N	NE	E	SE	S	SW	W	NW	Windless
U cesty	4.54	8.89	11.58	8.57	16.24	19.41	19.86	10.32	0.59
Kozinec	6.99	13.96	10.61	9.91	10.52	26.39	12.39	8.55	0.67

Wind speed was ranging from 0.0 m/s to 7.5 m/s in U cesty and 0.0 to 7.5-10.0 in Kozinec. Most frequent wind speed was in the 0.5-2.5 m/s category as shown in Table 2 [13].

Table 2. *Wind speed percentage*

Subsidence	0.0-0.5 m/s	0.5-2.5 m/s	2.5-7.5 m/s	7.5-10.0 m/s
U cesty	32.50	60.06	7.43	0.00
Kozinec	28.65	60.14	11.19	0.01

Long-term precipitation normal in the studied area is 802 mm a year. Precipitation in the year of study was 798 mm with an unusually high precipitation in the months of January (151 % of normal) and May (152 %) followed by June and July with lower-than-normal precipitation [13].

2.2 Seed rain collection

Sampling was conducted in 2019, when 15 seed traps were placed in selected plots of each subsidence basin. Plot selection was based on the inclusion of different habitats around subsidence basins (overburden, forest, wetland). Exact coordinates in WGS84 are shown in Table 3. Funnel seed traps were used for seed rain collection. Seed traps, consisting of 35 cm diameter plastic funnel with a surface area of 0.096 m^2, were inserted into a perforated polypropylene pipe at an approximate height of 0.5 m. Mesh was attached to the inside end of the pipe for seed capturing. Traps were checked monthly since May 2019 to November 2019 and their content was collected and analysed. Litter was discarded and seeds were determined and counted. Results were converted into seed densities

Vol. 67 (2021), No. 3
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(seeds/m²) by multiplying the total number of collected seed of each species by 10.417 and divided by the number of sampling conducted.

Table 3. *Seed traps coordinates*

Sampling plot	**Latitude**	**Longitude**
U cesty 1	49.81337	18.47723
U cesty 2	49.81352	18.47719
U cesty 3	49.81189	18.47753
U cesty 4	49.81198	18.4775
U cesty 5	49.81211	18.47773
U cesty 6	49.81211	18.47758
U cesty 7	49.81224	18.47807
U cesty 8	49.81222	18.47677
U cesty 9	49.81358	18.47742
U cesty 10	49.81368	18.47744
U cesty 11	49.8136	18.4777
U cesty 12	49.81156	18.47746
U cesty 13	49.81369	18.47765
U cesty 14	49.81373	18.47783
U cesty 15	49.81358	18.47785
Kozinec 16	49.86957	18.4872
Kozinec 17	49.86969	18.48744
Kozinec 18	49.86982	18.48753
Kozinec 19	49.8695436	18.4873175
Kozinec 20	49.8695	18.48724
Kozinec 21	49.8694728	18.4871847
Kozinec 22	49.86954	18.48692
Kozinec 23	49.8695	18.48684
Kozinec 24	49.86955	18.4868
Kozinec 25	49.86962	18.48696
Kozinec 26	49.86965	18.48702
Kozinec 27	49.8697	18.4873
Kozinec 28	49.86976	18.48717
Kozinec 29	49.8698	18.48697
Kozinec 30	49.86984	18.48669

2.3 Data analysis

Species diversity of above-ground vegetation was calculated using Shannon-Wiener diversity index according to Formula 1:

$$H' = -\sum_{n=1}^{n}(pi * ln\, p_i) \qquad \textbf{(1)}$$

where H' is Shannon-Wiener diversity index, and p_i is the proportion of individuals of the i-th species [14].

To compare the similarity between seed rain and above-ground vegetation, the Jaccard similarity index was used, according to Formula 2:

Vol. 67 (2021), No. 3
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$$J(A,B) = \frac{|A \cap B|}{|A \cup B|} \qquad (2)$$

where *J (A,B)* is Jaccard index of similarity between two sets, $|A \cap B|$ is the number of shared species in above-ground vegetation and seed rain, and $|A \cup B|$ is the number of un-shared species in above-ground vegetation and seed rain [15].

Similarities between the seed rain of individual seed traps and above-ground vegetation in their vicinity (10 m^2), as well as similarity between the whole seed rain and plant communities and seed rain and communities only of woody species were compared.

Dispersal strategies of above-ground vegetation and seed rain species was assessed according to Sádlo et al. [16]. All statistics were compiled in R 4.0.3 software [17].

3 RESULTS

Total amount of 11782 seeds representing 14 plant families, 24 genera and 27 plant species were collected from the seed traps during the study. Mean seed abundance (±SD) per seed trap was 392.7 ± 921.7 (Figure 1). The number of seeds captured in the Kozinec subsidence basin was three times higher than U cesty. Woody plants dominate in the seed rain, making up 97.85 % of captured seeds. *Salix alba* species prevails as it makes up 83 % of captured seeds. Mean seed density was 1162 seeds/m^2 ± 2543 with minimum of only 7 seeds/m^2 and maximum of 12380 seeds/m^2 (Figure 1). Mean density per individual subsidence basin was 531 seeds/m^2 ± 1279 at U cesty and 1792 seeds/m^2 ± 3242 at Kozinec.

Table 4. *Seed rain composition*

Species	**Family**	**SeedN**[a]	**DisStrb**[b]
Sambucus nigra L.	Adoxaceae	10.42	Cornus
Daucus carota L.	Apiaceae	5.21	Bidens
Pilosella caespitosa (Dumort.) P. D. Sell et C. West	Asteraceae	537.33	Epilobium
Cirsium palustre (L.) Scop.	Asteraceae	8.68	Epilobium
Picris hieracioides L.	Asteraceae	5.21	Epilobium
Impatiens glandulifera Royle	Balsaminaceae	97.22	Allium
Betula pendula Roth	Betulaceae	2726.56	Epilobium
Alnus glutinosa (L.) Gaertn.	Betulaceae	1993.06	Epilobium
Carpinus betulus L.	Betulaceae	32.12	Epilobium
Robinia pseudoacacia L.	Fabaceae	109.37	Allium
Vicia cracca L.	Fabaceae	9.55	Allium
Lathyrus pratensis L.	Fabaceae	6.94	Allium
Tilia platyphyllos Scop.	Malvaceae	229.17	Epilobium
Fraxinus excelsior L.	Oleaceae	11.28	Epilobium
Epilobium sp.	Onagraceae	3.47	Epilobium
Larix decidua Mill.	Pinaceae	2.60	Epilobium
Calamagrostis epigejos (L.) Roth	Poaceae	13.02	Epilobium
Arrhenatherum elatius (L.) J. Presl et C. Presl	Poaceae	306.42	Allium
Alopecurus pratensis L.	Poaceae	23.44	Allium
Agrostis sp.	Poaceae	177.95	Allium
Prunus avium (L.) L.	Rosaceae	31.25	Cornus

Vol. 67 (2021), No. 3
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DOI 10.35180/gse-2021-0055

Rubus idaeus L.	Rosaceae	3.47	Cornus
Salix alba L.	Salicaceae	28448.78	Phragmites
Acer platanoides L.	Sapindaceae	16.49	Epilobium
Acer pseudoplatanus L.	Sapindaceae	11.28	Epilobium
Acer campestre L.	Sapindaceae	10.42	Epilobium
Acer negundo L.	Sapindaceae	20.83	Epilobium

[a] SeedN is a total number of seeds per meter squared. [b] DisStrb is species dispersal strategy according to Sádlo et al. [16].

Mean species richness among traps was 4 ± 2 with a range of 1–10 species (1–5 at U cesty and 1–10 at Kozinec). Seeds of invasive *Impatiens glandulifera*, *Robinia pseudoacacia*, *Arrhenatherum elatius, Acer negundo,* species with up to a massive impact on the environment [18], and expansive plant species *Calamagrostis epigejos* were identified in the seed rain. Seeds of *Robinia pseudoacacia* were collected at three plots located at the forest of the Kozinec subsidence basin, with the number of seeds captured ranging from 3 to 26, which accounted for 2–22% of the seeds captured in each trap. Seeds of both *Impatiens glandulifera* and *Arrhenatherum elatius* were also collected only at Kozinec, in three traps located at the littoral zone. 3–15 seeds of *Impatiens glandulifera* (2.1–14.1 % of captured seeds) and 7–46 *Arrhenatherus elatius* seeds (8.2–26.1%) were collected at these traps. Only 4 seeds of *Acer negundo* were collected in a single trap of west part of U cesty subsidence basin. 1 and 3 seeds of *Calamagrostis epigejos* were found at two traps located at the grassland in the south of U cesty subsidence basin and in the littoral of Kozinec.

Species found in seed traps accounted for 27.6 % of plant species at the community level of both subsidence basins. When only woody species were compared, 15 of identified seeds species accounted for 52 % of woody species at community level. Most of the seeds are dispersed at a distance higher than 10 m since median of Jaccard index between each trap and vegetation in given distance was 0.09 (Figure 1).

Plant species whose seeds were found in seed traps utilize Allium, Bidens, Cornus, Epilobium and Phragmites dispersal strategies. Most of the trapped seeds belongs to the Phragmites strategy, thanks to *Salix alba* species. 55 % of species in the seed rain utilize Epilobium strategy. In the above-ground vegetation, more strategies are utilized – Allium, Bidens, Cornus, Epilobium, Phragmites, Lycopodium, Sparganium and Zea strategies, with 47 % of species using Allium dispersal strategy.

Mean H′ of above-ground vegetation was 1.97 ± 0.46 on both subsidence basins (Fig 2). Above-ground vegetation of subsidence basin U cesty is more diverse (H′ 2.16 ± 0.43) than Kozinec (H′ 1.78 ± 0.42). In total, 73 plant species were identified in above-ground vegetation of U cesty as well as in Kozinec, including invasive species: *Arrhenatherum elatius*, *Solidago canadensis*, *Ailanthus altissima*, *Reynoutria japonica*, *Acer negundo*, *Impatiens parviflora* and *Robinia pseudoacacia*. Only few individuals of these invasive species were recorded, with *Arrhenatherum elatius* and *Solidago canadensis* having the most cover and abundance. Expansive *Calamagrostis epigejos* was more prominent in above-ground vegetation, with appearance in 12 of 30 plots and coverage of 25–30 % at three plots (southern grassland at U cesty) and 5–25 % coverage at another two plots (verge of forest and littoral at northern part of U cesty and grassland at Kozinec).

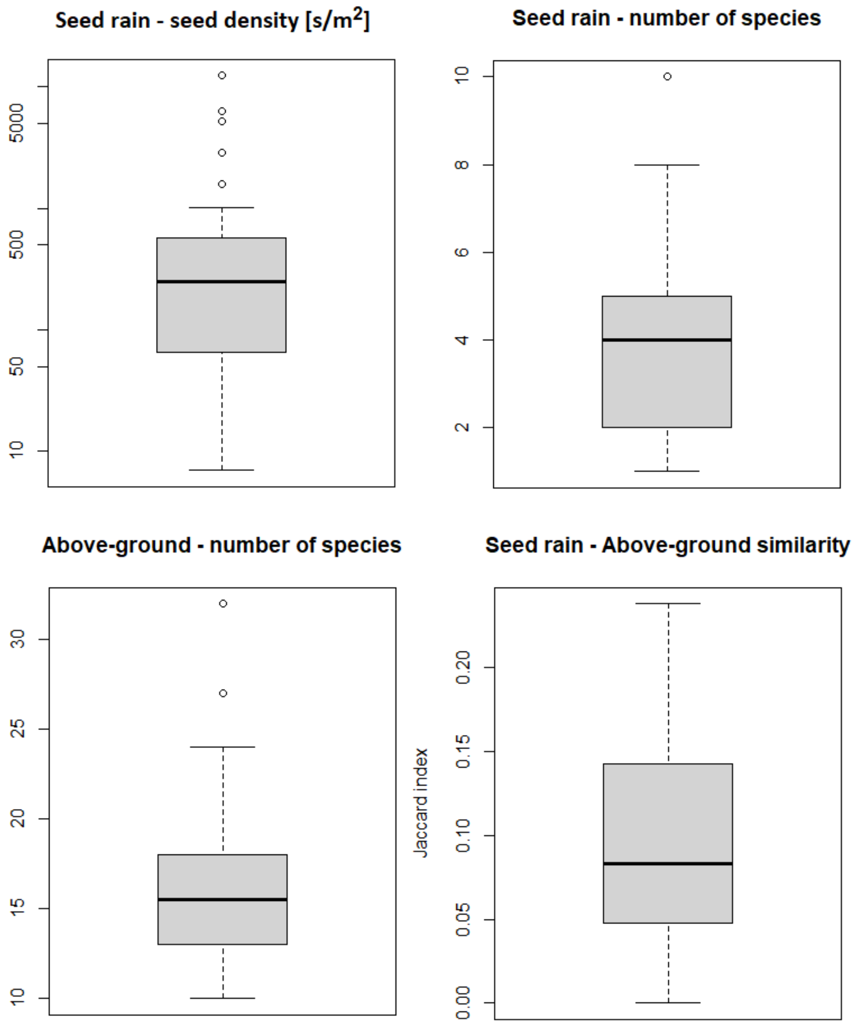

Figure 1. *Box-plot graphs of selected characteristics*

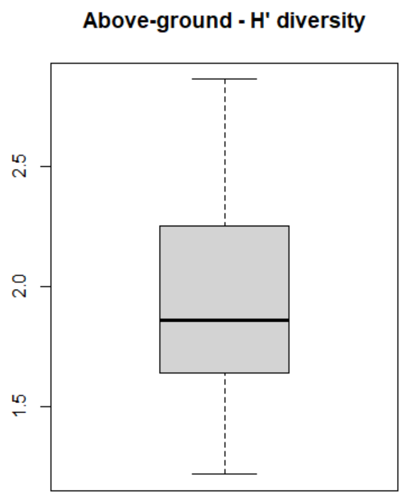

Figure 2. *Box-plot graph of above-ground diversity*

Vol. 67 (2021), No. 3
pp. 85–94, ISSN 1802-5420
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4 DISCUSSION

The maximum of seed rain density was achieved from May to August and decreased significantly in the following months. This is in line with the results provided by Jensen [19] in abandoned wet meadows. The results show that seed rain is dominated by several species, a frequent phenomenon of many studies with many different dominating species, for example *Cardaminopsis arenosa* and *Silene vulgaris* on recent zinc mine spoils in Poland [9], *Scirpus sylvaticus*, *Juncus effusus*, *Urtica dioica* in abandoned wet meadows in Germany [19], *Leontodon hispidus* in calcareous grasslands of Netherlands [20], *Thymus cf. polytrichus*, *Gnaphalium supinum* in grasslands of Switzerland [21].

Outliers occur on five plots within the recorded seed density. One at grassland in the south of U cesty subsidence basin and four at the forest of the eastern slope transect of the Kozinec subsidence basin. Seed rain is dominated by *Salix alba* (seed density ranging from 2646 to 12065 seeds/m^2) and *Betula pendula* species (1250 seeds/m^2) here. The location of these plots is near *Salix sp.* adults, which may lead to excessive seed accumulation in seed traps. The dominance of the *Betula pendula* species on one Kozinec plot is unusual, since it was not recorded in the above-ground vegetation in the study area of this subsidence basin. However, the maximum theoretical dispersion distance of a 20-m individual in a 5 m/s wind reaches 192 m and thousands of seeds/m^2 was recorded at distance of 40 m [22].

The diversity of the habitats of the study area and proximity of trees with high seed production possibly causes a high heterogeneity of the seed density results. The coefficient of variation (CV) of seed density reaches the value 2.2 (2.4 U cesty, 1.8 Kozinec). There is a clear difference in the seed density of forest (mean seed density 1428 seeds/m^2 ± 3057, CV 2.14) and other habitats (mean seed density 825 seeds/m^2 ± 1373, CV 1.66). The impact of *Salix alba* species on the heterogeneity of seed density in the study area is significant. The removal of this species from the results reduces the mean seed density to 213 seeds/m^2 ± 293 with CV of 1.37 (mean seed density 118 seeds/m^2 ± 138 and 1.17 CV at U cesty; 309 seeds/m^2 ± 367 and 1.19 CV at Kozinec).

Outliers of the number of species in seed rain are recorded in the forest part of Kozinec subsidence basin, where 9 out of 10 seed rain species are woody species. On average, more seed rain species were trapped in forest habitats (4.3 ± 2.1) than in other habitats (3.8 ± 2.1). The 0.5 m height of the seed traps might contribute to this trend, as the number of trapped seeds of local herbaceous species could be limited.

The number of collected seeds may also be undervalued since the collection took place only from May to November of one year. Therefore, seeds dispersed through the winter could not be captured and the possibility of masting year, spread mainly in long-lived woody and wind-pollinated species [23], is not considered. The variability in seed production is influenced by climatic factors, available sources and by evolution of reproductive strategies, mainly trying to improve success of wind pollination by larger flowering efforts and satiate predators by increasing seed production [24] According to the information on forests and forestry in the Czech Republic, the year of this study was characterized by below the average seed production of the main forestry species [25]. Most of the collected seeds in this study were from woody species, the population of which produces a copious number of seeds every year like *Betula pendula [26]* and *Salix alba* [27].

4.1 Seed rain and above-ground vegetation similarity

Similarity between each seed trap and above-ground vegetation in 10 m radius tends to be very low, with a range from 0 to 0.214 and mean value of 0.09. Similarity increases when comparing the plant community of each subsidence basin with its seed rain to 20 % at U cesty and 22 % at Kozinec, while the plant communities of both basins with total seed rain increase similarity to 27.6 %. It is evident that the dispersal distances exceed 10 m, which corresponds to prevailing dispersal strategies. Similarity of above-ground vegetation and seed rain usually increase with decreasing dispersal distances [19]. Within the woody species, most species present in seed rain are also in above-ground vegetation, except for *Larix decidua*. Within the woody species community, similarity of seed rain and their above-ground vegetation is 52 %. A similar result to the Hardesty and Parker [28] in tropical forests and Wang [29] with the usage of 9-year data in temperate forest.

Vol. 67 (2021), No. 3
pp. 85–94, ISSN 1802-5420
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4.2 Dispersal strategies

In the above-ground vegetation of selected subsidence basins, the composition of individual dispersal strategies is alike their representation in the Czech Republic. The dominant (47% of species present in above-ground vegetation of subsidence basins) Allium strategy is also most frequent in the Czech Republic, where it represents approximately 56 % of the species assessed by Sádlo et al. [16]. This strategy is typical for species of mesic and arid habitats [16], which are represented in the study area by vegetation of habitats rehabilitated by overburden, forest, and grassland habitats. Epilobium and Cornus strategies are also significantly represented here. Despite the character of the research areas, strategies typical for wetlands, Phragmites and Sparganium are minimally present in the above-ground vegetation of subsidence basins. Also, Bidens, Lycopodium and Zea dispersal strategies are scarce and none of the species in the above-ground vegetation is represented by aquatic macrophytes of Wollfia strategy.

Composition of dispersal strategies is different in the seed rain. Most species present in seed rain uses Epilobium strategy (55 %), followed by Allium (26 %), Cornus (11 %), Bidens (4 %), and Phragmites (4 %). Due to properties of used seed traps, however, it is possible that woody species or tall herbs which use anemochory and autochory for the seed dispersal are more likely to be collected.

5 CONCLUSION

The seed rain in subsidence basins consists mainly of alluvial forests species (*Acer pseudoplatanus*, *Alnus glutinosa*, *Fraxinus excelsior*, *Salix alba*) with a dominance of *Salix alba*. Seeds of invasive and expansive species were found in the seed rain, yet their amount and frequency were not high. Seed densities are highly heterogenic, varying especially in the forest habitat of subsidence basins where tree traits can have higher influence on dispersal than seed traits. Similarity of seed rain and above-ground vegetation tends to be very low in small distances and gets higher when compared on the scale of communities – 27.6% for all plant species and 52 % for woody species. Composition of seed rain has shown that Epilobium and Phragmites strategies are the most successful in colonizing subsidence basins as many of their woody species of mesic and wet habitats produce numerous light seeds, capable of traversing long distances even in fragmented landscapes. Other strategies are not as successful in seed dispersal in these habitats. Higher number of seeds were captured only in species using Allium strategy – the most frequent strategy in Czechia with mostly generalists preferring mesic and dry habitats. Although these basins had largely been impacted by anthropogenic factors, there are little to no representation of Bidens and Zea dispersal strategies which are with Allium strategy typically overrepresented in anthropogenic vegetation.

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